

(Speculations on)

Human Health Risks of *Sewage Sludge*

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Approach

What's in *sludge*?

review of literature (mostly European)

Precautionary principle

Substance poses risk until
proven safe.

What are the **known & suspected, acute & chronic**
effects on humans?



We know (almost) nothing

Currently knowledge has 2 virtues:

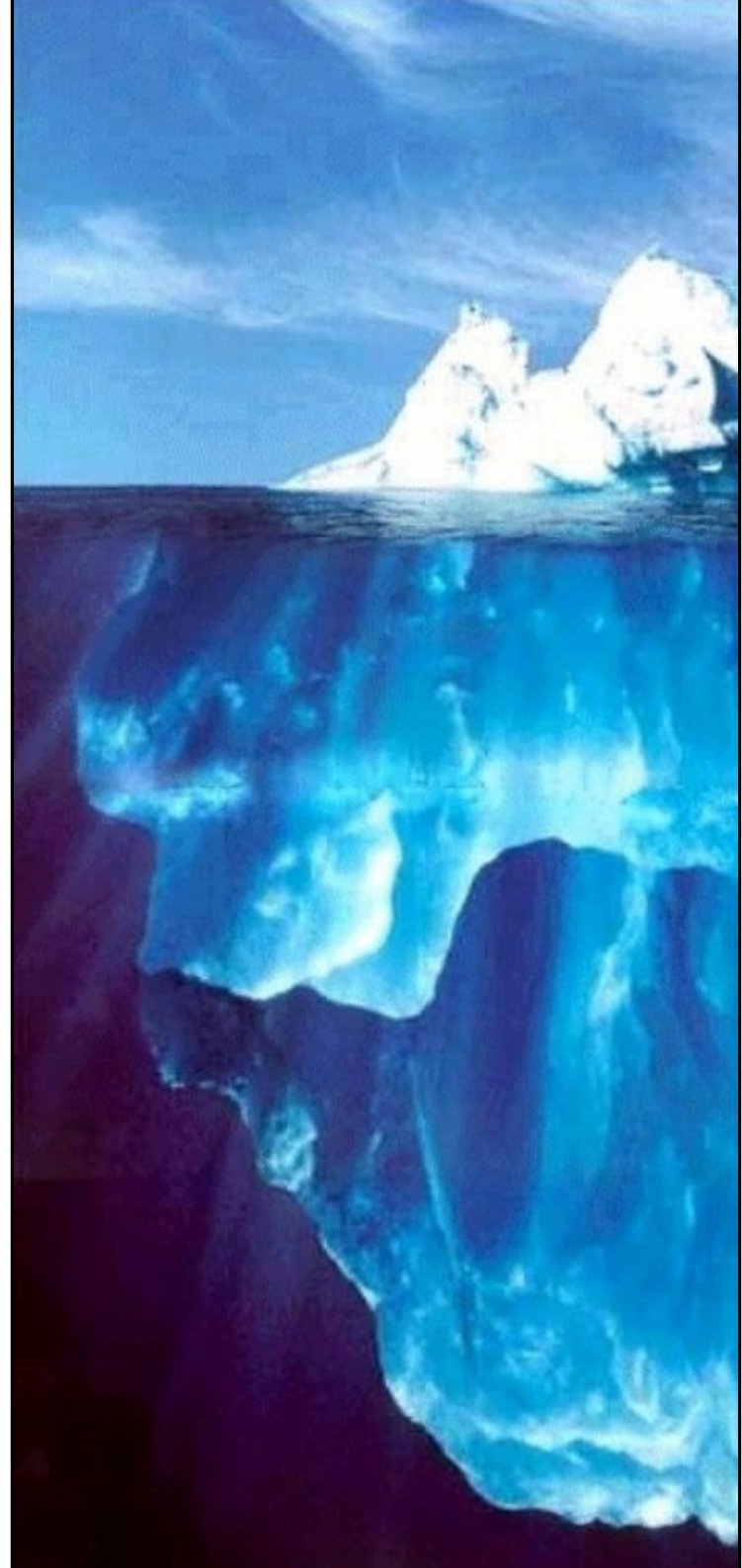
1. **Extremely limited**

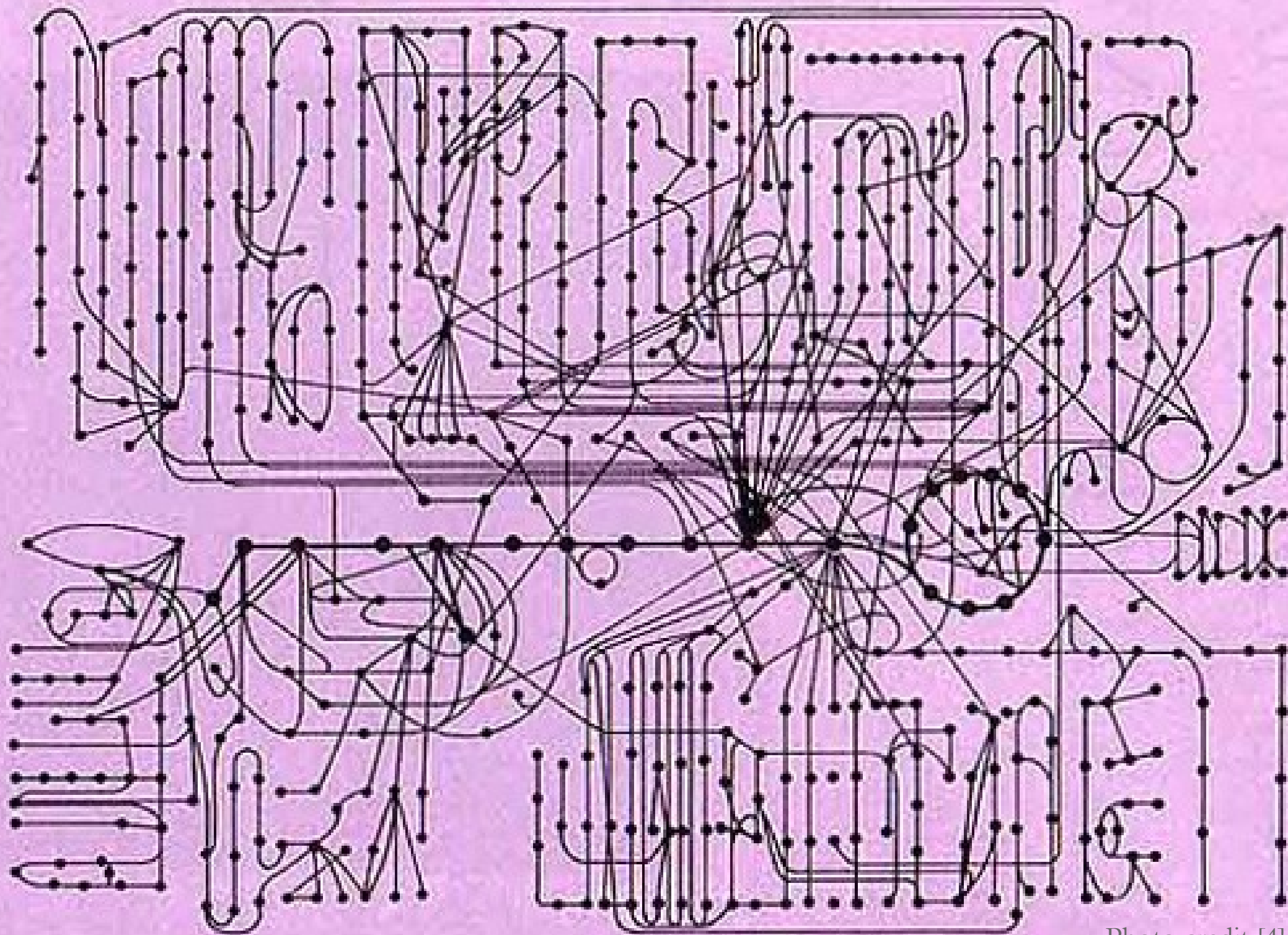
Vast networks of possible chemical reactions & interactions

2. **Mostly random**

Often based on technical convenience rather than relevance of question

More systematic approaches are relatively new (& mostly European)







I Background: Public Health & Toxicology

II Heavy Metals

Pb Zn Cd Cr Hg Cu Ni

III Organics

Pharmaceuticals & their derivatives

IV Special focus: **Antibiotics & Estrogens**

Review of Public Health



+



PROBLEM





Toxicology

Routes of Exposure

Topical

skin, eye, mucus membranes
(depending on activity)

Inhalation

aerosols, particles, gases

Ingestion

water, food, breast milk

Toxicology

Acute vs. Chronic Exposure

Acute Exposure

High dose & (usually) brief
Exposure & effect close in time



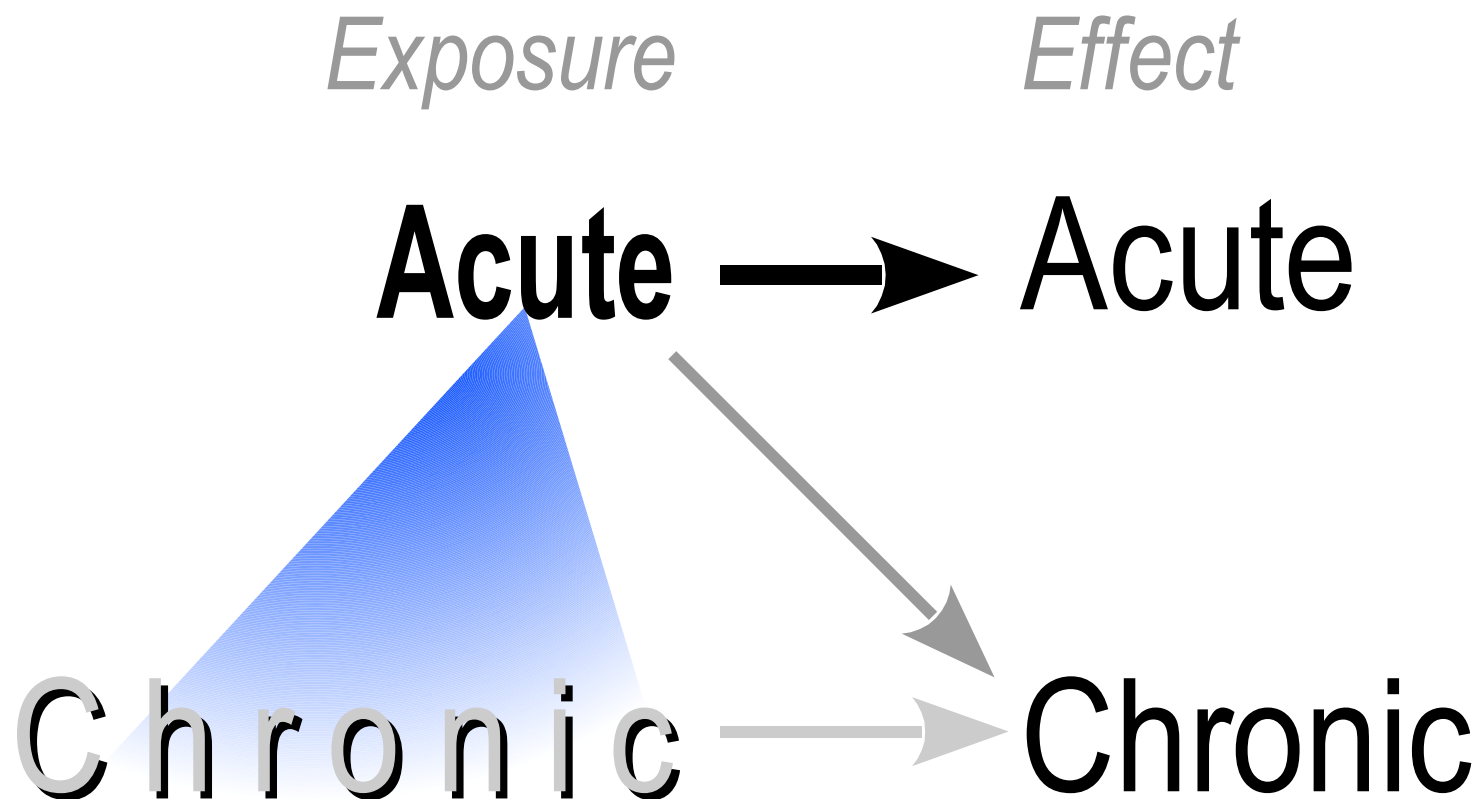
Chronic Exposure

Low dose & long-term
Exposure & effect far apart



Toxicology

Timescale of exposure & effect



Toxicology

Acute vs. Chronic Effect

Acute Effects

More active tissues at higher risk

Chronic Effects

Bioconcentration

Higher potential reproductive effects

Can affect different (slower) tissues:
neural tissue, bone

Acute effects often not predictive





Minamata Tomoko by William Eugene Smith, 1973

Toxicology

Factors determining Toxicity

Dose, Timing & Route

Tissues exposed & Level of exposure

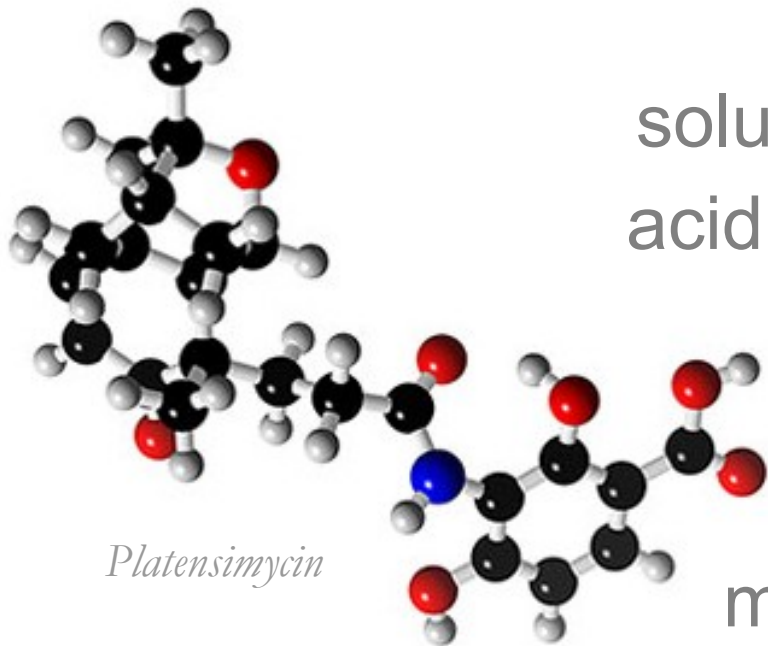
bioavailability & **bioconcentration**

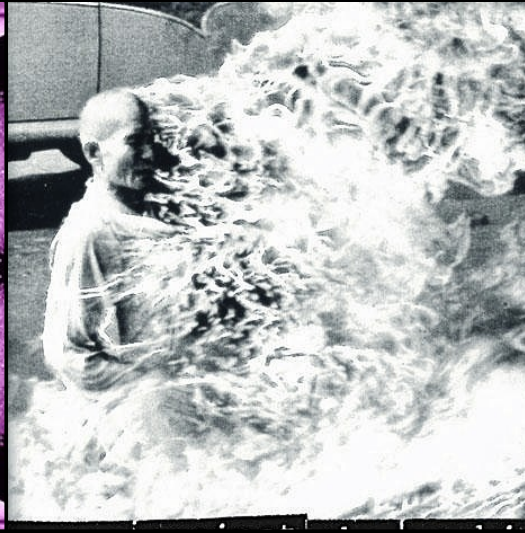
Toxin

solubility in water vs. fat
acidity, molecular weight

Organism

weight
metabolic capacity





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Heavy Metals

Culprits & Sources

Lead (Pb)

 Old pipes, paint, pool cue chalk

: Batteries, pigment, solder

Cadmium (Cd)

 Rechargeable batteries, paint, photography, washing powders

 Detergents, plastic manufacture, pigments, alloys, solders

Copper (Cu)

 Plumbing, fungicides, wood preservatives

 Electronics, plating, paper, textile, rubber

Mercury (Hg)

 Antibacterial soaps, old paints

 Dental, disinfectants, mirrors, electronic production, hospitals

Heavy Metals

Culprits & Sources

Nickel (Ni)

 Batteries, alloys

 Laundry, electroplating, hydrogenation of vegetable oils

Zinc (Zn)

 Cosmetics, Deodorants, anti-dandruff shampoo, medicine

 Galvanization, alloy production, tires, embalming, taxidermy

Chromium (Cr)

 Alloys, preservatives, dyeing, tanning



Heavy Metals

Points of Interest



Dishwashing by hand produces more heavy metal waste than by machine

Feces contributes 20% of **Cu**, **Cd**, **Ni**
& 28% of **Zn**

Hard water (low pH - acid) dissolves **Cu** & **Pb**
Soft water (high pH - alkali) dissolves **Zn**

Sources:

Domestic, Urban Runoff, Car-related, Industrial



Heavy Metals
Sources:
Urban Runoff

$\text{Cd} \ll \text{Cu} < \text{Pb} < \text{Zn}$

Roofs & streets seem to
have the worst effects. Some
Pb paints still in use.



Roofs
Mostly **Zn & Cu**, some Cd



Heavy Metals **Vehicles & Roads**

Major Contributors

Brakes (Pb, Cu, Zn, Ni) & **Tires** (Zn)

Minor Contributors

Bumpers & window sealant (Ni, Cr)

Fluid losses (oils, coolants)

Fuel (now mostly unleaded)

Modifying Factors

Car-wash **detergent** stabilizes metals in wastewater making them harder to eliminate

Salt facilitates release of metals (mostly **Pb**) from sludge

Heavy Metals

Environmental Toxicity

Zn

Micronutrient: plants need min 15mg/kg to grow

Phytotoxic at high levels (~ 400mg/kg)

Phytotoxic effects before toxicity in animal tissue:
~1000mg/kg needed for significant transfer to animals

Cu

Micronutrient: normal level in plants is 5-25mg/kg

Phytoxic at high levels (~ 2000mg/kg)



Heavy Metals Environmental Toxicity

Cr

Low solubility → low bioavailability
Very little toxicity observed in crops
grown high Cr

Pb

**Toxic to plants & animals at
any concentration**

Plants tolerate it well due to
adsorption to soil

Main concerns:
**soil ingestion by livestock &
children**

Heavy Metals

Environmental Toxicity



Cd

Phytotoxic under **acidic** conditions
Bioconcentration varies according species
of plant



Hg

Highly toxic to animal **neural tissue**
Accumulates in **fat-rich** tissues
~**80%** can be bound to **non-bioavailable**
compounds

Heavy Metals: Health Effects

Lead (Pb)

Adults

Headache, fatigue
digestive system complaints
poor concentration & sleep
Progresses to **anemia**
neurological problems
renal failure, hypertension

Children

Neuro-behavioural problems
delayed weaning

Testing

Whole blood level
max: 10mcg/dL (child); 20mcg/dL (adult)



Heavy Metals: Health Effects

Copper (Cu)

Adults & Children

Micronutrient

Competes with **Zn** for absorption

Digestive system complaints

Headache, fatigue

Progresses to hemolytic **anemia**

jaundice, hemoglobinuria

Excreted in bile

Upper limit: 10-12mg/day (WHO)





Heavy Metals: Health Effects

Zinc (Zn)

Adults & Children

Micronutrient

Competes with **Cu** for absorption from gut

Digestive system complaints, **Cu** deficiency, decreased HDL cholesterol

Testing

Difficult: plasma levels do not correlate well with tissue

Can measure indirectly via enzyme function

Max intake: 150-450 mg/day

Heavy Metals: Health Effects

Cadmium (Cd)

Readily absorbed by **plants** from **soil**
(especially rice, grain & vegetables)

Metallothionein* overwhelmed

** binds many metals & is believed to be involved in regulating metallic micronutrients as well as protection against metal toxicity*

Adults & Children

Kidney damage, osteopenia &
osteoporosis

Testing

Urine test for beta-2 microglobulin

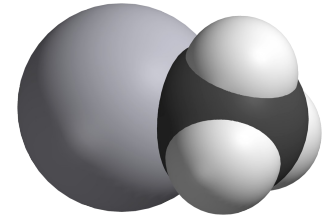




Heavy Metals: Health Effects

Mercury (Hg)

Highly toxic



Organic

bound to organic compound e.g. methylmercury

“Minamata Disease”. Neurological effects.

Readily crosses the placenta (teratogenic)

Fish, antiseptics, embalming, detergents, diapers
paper manufacturing

Elemental or Inorganic

Kidney failure, dementia, acrodynia

Perfume industry, batteries, cosmetics
disinfectants, embalming, ink manufacturing



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II Heavy Metals

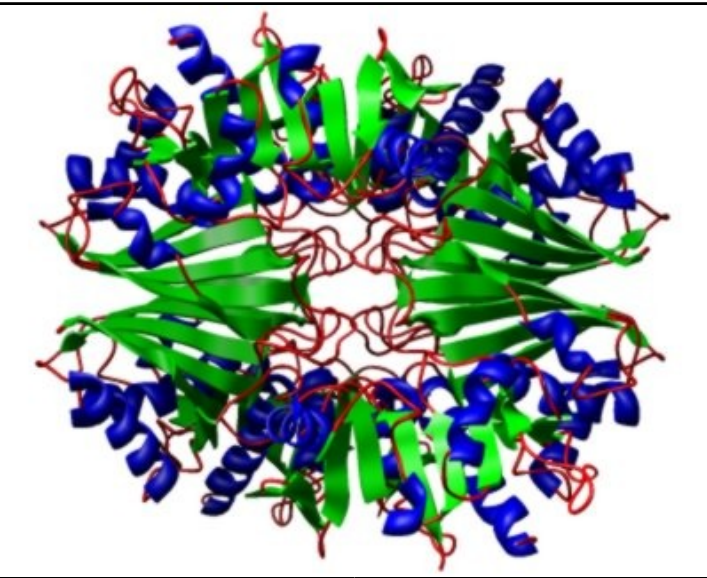
Pb Zn Cd Cr Hg Cu Ni

III Organics

Pharmaceuticals & their derivatives

IV Special focus: Antibiotics & Estrogens

Health Consequences of Biologicals



60-80% of sludge consists of organic matter

Thousands of organic chemicals

Most are lipophilic & can **bioaccumulate**

Unpredictable chemical interactions in environment

Possible **exposure** through **meat** and **dairy** products if applied to grazing land

Difficulties in testing

Little or no toxicity data for long-term, low dose exposure

Organics

Polyaromatic Hydrocarbons (PAH)

Sources

Created by burning wood, carbon, oils, etc.
Car exhaust particles, food preparation, house
& forest fires, industrial plants

Effects of chronic exposure

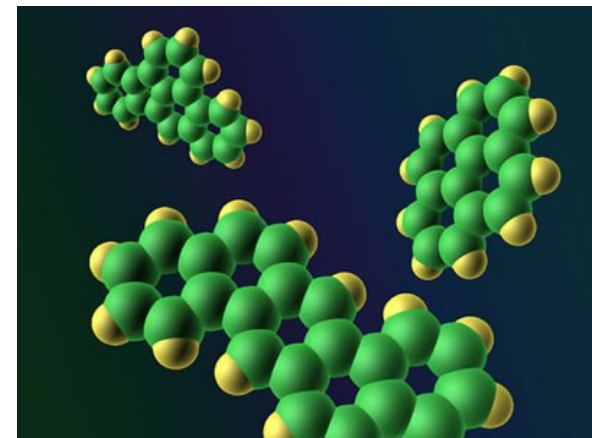
developmental & reproductive effects
possibly carcinogenic

Disposition in environment

Low biodegradability

Concentrate in sewage sludge

Bioconcentration



Organics

Di-(2-ethylhexyl)phthalate (DEHP)

Sources

Paper production, plastics (softner)
cosmetics, perfumes, pesticides

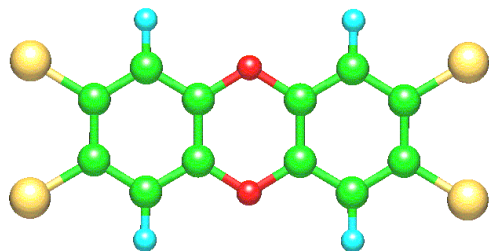
Effects of chronic exposure

damage to **liver & testes**, **birth defects**
affect **thyroid hormone** levels
possibly carcinogenic

Disposition in environment

adsorbs to soil & sediments
bioconcentrates due to high fat solubility





Organics

Dioxins

Sources

By-products of incomplete combustion processes involving chlorine

Effects of chronic exposure

Suppression of **hormonal** & **immune** systems

Teratogenic

Spontaneous **abortions**

Alterations in **glucose metabolism**

Carcinogenic in humans



Organics

Pharmaceuticals

Sources

Human & animal therapies

Effects of chronic exposure
unknown

Large & increasing **variety**

Many end up in sludge

Potential to **bioaccumulate**

Many excreted in active forms

Can be **reactivated** during treatment

Unpredictable & potentially **toxic**
metabolites

Combinations may have
unpredictable synergistic effects



Organics

Antineoplastic agents

Commonly used as cancer
chemotherapy

**Carcinogenic &
Teratogenic**

**Effects at very low
concentrations**





I Background: Public Health & Toxicology

II Heavy Metals

Pb Zn Cd Cr Hg Cu Ni

III Organics

Pharmaceuticals & their derivatives

IV Special focus:
Antibiotics & Estrogens

Antibiotics: Sources & Forms

Sources

Human & Veterinary

Forms

Parent compound

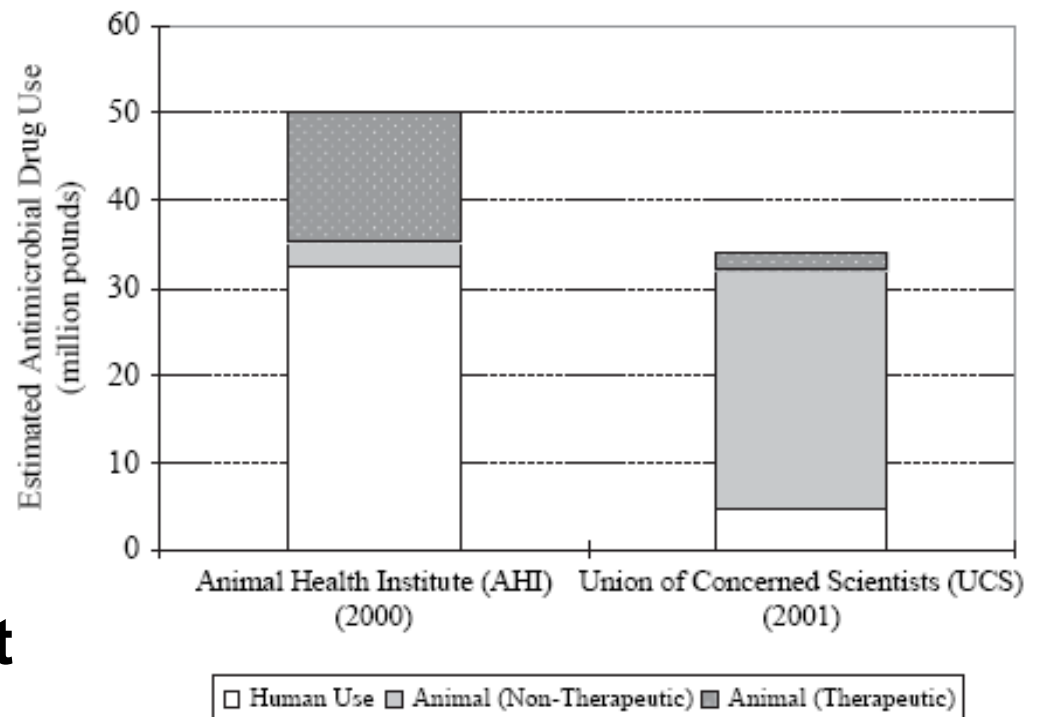
Metabolites

Post-excretion derivatives*

Activity of metabolites & derivatives depends on **context**

Derivatives & activity very **unpredictable**

Fig 1: Estimates of Abx use in the US [1]



Antibiotics

Potential Routes of Exposure

Wastewater treatment plants

Manure or

Sewage *sludge* application

Inhalation of **aerosolized** particles

Topical contact

Ingestion



Antibiotics Concentrations in Wastewater

From Kim *et. al.* 2007 [1]

Antibiotic	Maximum concentration observed (µg/L)	Country	Reference
Amoxicillin	150	United States	Morse and Jackson (2003)
Chlortetracycline	1.2	United States	Karthikeyan and Bleam (2003)
	2.8 ^a	United States	Glassmeyer et al. (2005)
Ciprofloxacin	0.6	Switzerland	Golet et al. (2003)
	1.4, 0.5 ^a	United States	Aga et al. (2006)
Clarithromycin	0.3	Switzerland	McArdell et al. (2003)
Erythromycin-H2O	6.0 ^a	Germany	Hirsch et al. (1999)
	0.6 ^a	United States	Glassmeyer et al. (2005)
Gentamicin	7.6	Germany	Löffler and Ternes (2003)
Norfloxacin	0.5	Switzerland	Golet et al. (2003)
Sulfamethoxazole	2.8, 0.7 ^a	United States	Aga et al. (2006)
	0.8 ^a	United States	Glassmeyer et al. (2005)
Tetracycline	4	United States	Karthikeyan and Bleam (2003)
	1.1, 0.3 ^a	United States	Aga et al. (2006)
	0.4 ^a	United States	Glassmeyer et al. (2005)
Trimethoprim	7.9, 2.4 ^a	United States	Aga et al. (2006)

^aAntibiotic concentration in treated wastewater.

Antibiotics

Are they in the environment?

What we know

Present in both **treated** & **untreated** wastewater

Concentrations in treated < untreated → partial removal

Hence in *sludge*

Low concentrations, continuous discharge

Limitations

Only **parent** compounds measured

Metabolites & bioactivity not addressed



Antibiotics

Biodegradation Scenarios

Mineralization to carbon dioxide

Transformation to ...

... **hydrophobic** (fat soluble) compounds

Partition onto activated *sludge*: Ciprofloxacin, Tetracycline

... or **hydrophilic** (water soluble) compounds

Remain in **water**: Sulfamethoxazole, Trimethoprim

Antibiotic Resistance Mechanisms

1. **Vertical** gene transfer: natural selection

2. **Horizontal** gene transfer: Conjugation,
Transduction (by bacterial viruses or plasmids)

Wastewater: optimum environment for both
Higher rates demonstrated downstream of wastewater
discharge

Sludge?

Higher concentrations of agents than wastewater
Antibiotics retain activity in soil

Antibiotics

Potential Human Impacts

Antibiotic resistance

Endocrine disruption

Estrogen

Thyroid

Glucose control

Effect on normal **gut bacteria** & nutrition ?

Immune & allergenic effects ?

Antibiotics

Impacts on Human Populations

In general we really have no idea

Antibiotics are **present** in waste water

Parent compounds are found after treatment

Increased antibiotic **resistance** has been
demonstrated

Little data to quantify **long term effects**

Special Focus

Endocrine Disrupting Compounds

Estrogen-related compounds most studied

Natural & synthetic estrogens

Birth control, hormone replacement
chemotherapy agents, phytoestrogens ...

Can **stimulate** or **block** estrogen activity

Special Focus

Endocrine Disrupting Compounds

May be related to increasing rates of
male infertility

Can contribute hormone dependent **cancers**

Highly **persistent in environment**
& sewage *sludge*

Enter & climb food chain: **bioconcentration**

Effects at very low concentrations

Recap



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PROBLEM



We know (almost) nothing

Currently knowledge has 2 virtues:

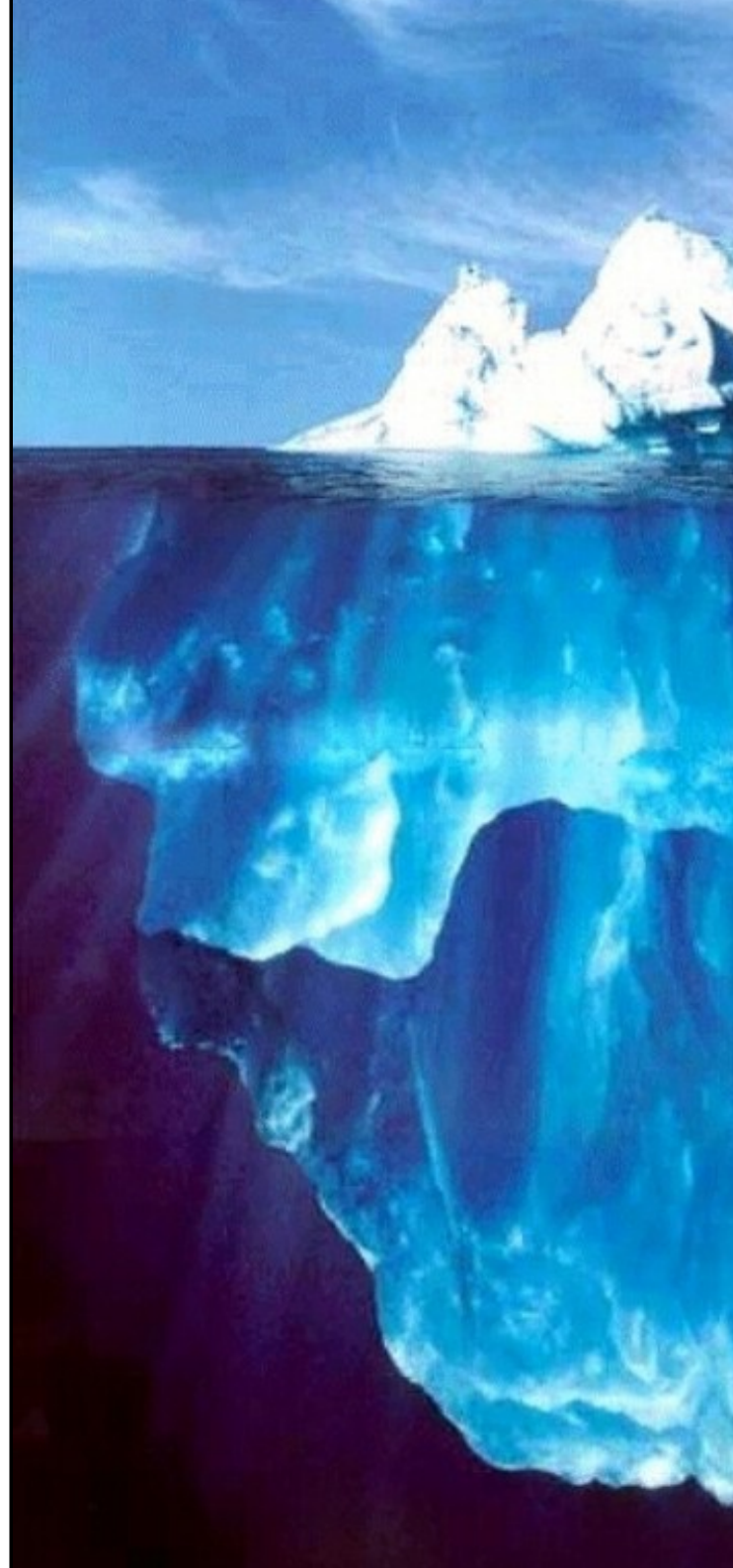
1. **Extremely limited**

Vast networks of possible chemical reactions & interactions

2. **Mostly random**

Often based on technical convenience rather than relevance of question

More systematic approaches are relatively new (& mostly European)



The Unknown

As we **know**,
There are **known knowns**.
There are things we **know** we **know**.
We also **know**
There are **known unknowns**.
That is to say
We **know** there are some things
We do not **know**.
But there are also **unknown unknowns**,
The ones we don't **know**
We don't **know**.

-- Sec. Donald Rumsfeld. *Feb. 12, 2002,*
Department of Defense news briefing



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- [8] Memorial to John Snow and his 1854 study in the place of the water pump on Broad Street (now Broadwick Street): a water pump with its handle removed, near what is now "The John Snow" public house. The spot where the pump stood is covered with red granite. Source: http://en.wikipedia.org/wiki/Image:John_Snow_memorial_and_pub.jpg. Copyright: creative commons license cc-by-sa
- [9] A carving of an American native mask found in Masset on Graham Island, Queen Charlotte Island, British Columbia. Source: <http://www.hickerphoto.com/american-native-mask-8068-pictures.htm>. Copyright: © Rolf Hicker. Used without license under fair use for non-profit educational purposes.
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- [12] The Madhatter by John Tenniel. Illustration from Lewis Carroll's Alice in Wonderland. Source: <http://www.gimmiesometruth.com/>. Copyright: Public Domain.
- [13] "Tomoko Uemura in Her Bath" by W. Eugene Smith, Minamata, Japan 1972. Tomoko Uemura's was exposed to toxic levels of mercury in utero. "Minamata disease" was first seen in Minamata city in Kumamoto prefecture, Japan in 1956. It was caused by the release of methyl mercury in the industrial wastewater from the Chisso Corporation's chemical factory, which continued from 1932 to 1968. This highly toxic chemical bioaccumulated in shellfish and fish in Minamata Bay and the Shiranui Sea, which when eaten by the local populace resulted in mercury poisoning. While cat, dog, pig and human deaths continued over more than 30 years. As of March 2001, 2,265 victims had been officially recognised (1,784 of whom had died). (http://en.wikipedia.org/wiki/Minamata_disease) Source: http://www.masters-of-photography.com/S/smith/smith_minamata_full.html. Copyright: © The Heirs of W. Eugene Smith. Used without license under fair use for non-profit educational purposes.
- [14] Structure of the antibiotic platensimycin, the first of a new class of antibiotics in over 40 years. It was discovered by Merck scientist Jun Wang and over 35 of his Merck colleagues, after they systematically screened 250,000 compounds extracted from microorganisms for antibiotic properties, Platensimycin, isolated from a strain of bacterium *Streptomyces platensis* found in a soil sample from South Africa. Source: <http://www.3dchem.com/molecules.asp?ID=271>. Copyright: © 2005-2007 Karl Harrison. Used without license under fair use for non-profit educational purposes.

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- [17] Cover of Rage Against the Machine's 1992 self-titled album, portraying a portion of Malcolm Browne's Pulitzer Prize winning photograph of the self-immolation of Thích Quảng Đức, a Vietnamese Mahayana Buddhist monk who burned himself to death at a busy Saigon road intersection on June 11, 1963. Thích Quảng Đức was protesting the persecution of Buddhists by South Vietnam's Ngô Đình Diệm administration. Source: <http://en.wikipedia.org/wiki/Image:Burningmonk.jpg>. Copyright: Unknown. Used without license under fair use for non-profit educational purposes.
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- [42] Donald Rumsfeld at the Pentagon. Source: <http://www.allhatnocattle.net/archives-StarWars.htm>. Copyright: Unknown. Used without license under fair use for non-profit educational purposes.